chapter

# 12 Excretory System

## In this chapter



In August 2000, Canadians Peter Reid and Lori Bowden won the Ironman Canada Triathlon men's and women's titles, completing the gruelling 226-km swim–cycle–run in 8 h, 29 min, and 49 s and 9 h, 17 min, and 23 s, respectively (**Figure 1**). The husband-and-wife team, dubbed "the world's fittest couple," went on to further victories: Peter once again won the Ironman Canada Triathlon in August 2001, and Lori won her third straight women's crown at the Australian Ironman competition in April 2001.

Imagine completing a 4-km swim and a 180-km bicycle ride only to have a 42-km marathon ahead of you. To meet the demands of this challenging competition, the body undergoes a series of adjustments to continue operating. One such adjustment is an increase in the rate of cellular respiration; another is a decrease in urine output.

The oxidation of glucose during cellular respiration generates waste energy in the form of heat. During severe strenuous exercise, body temperature can increase to more than 39 °C. To dissipate heat, sweat is produced.

The evaporation of sweat is a cooling process. The loss of water alters the volume of body fluids, which can cause a drop in blood pressure. The heart and circulatory system respond to changes in blood pressure, while the kidneys conserve water in an attempt to maintain fluid volume.

Water is not the only thing lost with sweating; many ions essential for nerve function and muscle contraction are carried to the skin with the perspiration. The kidneys are also responsible for maintaining the body's electrolyte balance.

## STARTING points

**Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.**

1. What dangers exist if your body is unable to regulate the fluid balance of your tissues?
2. What challenges would the body have to respond to if the kidneys failed to work?
3. Explain how the circulatory system and excretory system interact during exercise.

Career Connections:
Urologist; Emergency Medical Technician


**Figure 1**
Lori Bowden finished first in the women's Ironman Canada triathlon in 2000.

## Exploration — Making a Model of a Filtering Excretory System

You can create a model of a filtering excretory system.

**Materials:** funnel, aquarium charcoal, 2 small beakers, food colouring, non-absorbent cotton, ring stand

- Place a small piece of non-absorbent cotton in a funnel. Fill the funnel with aquarium charcoal, and put a small beaker beneath the funnel. Fill a second beaker with about 25 mL of water, and add five drops of food colouring.
- Pour the coloured water through the funnel and collect it in the beaker beneath as shown in **Figure 2**.

(a) Compare the colour of the filtered water with the original coloured water.
(b) Predict what will happen if the water is filtered once again. Test your prediction.
(c) How would you improve the filter?

**Figure 2**
Model of a filtering excretory system

# 12.1 Waste Excretion and Internal Equilibrium

**Figure 1**
The human kidney is about the size of a fist and weighs approximately 0.5 kg.

The cells of the body obtain energy by converting complex organic compounds into simpler compounds. However, many of these simpler compounds can be harmful. To maintain life processes, the body must eliminate waste products. The lungs eliminate carbon dioxide, one of the products of cellular respiration. The liver transforms ingested toxins, such as alcohol and heavy metals, into soluble compounds that can be eliminated by the kidneys. The liver also transforms the hazardous products of protein metabolism into metabolites, which are then eliminated by the kidneys (**Figure 1**). In fact, the kidneys play a crucial role in removing waste, balancing blood pH, and maintaining water balance.

The average Canadian consumes more protein than is required to maintain tissues and promote cell growth. Excess protein is often converted into carbohydrates. Protein, unlike carbohydrates, contains nitrogen. The amino group ($NH_2$) that is characteristic of amino acids must be discarded by the body.

This process, referred to as **deamination**, occurs in the liver. The byproduct of deamination is ammonia, a water-soluble gas. However, ammonia is extremely toxic—a buildup of as little as 0.005 mg can kill humans. Fish are able to avoid ammonia buildup by continually releasing it through their gills. Land animals, however, do not have the ability to release small quantities of ammonia throughout the day—it must be stored. Once again, the liver is called into action. In the liver, two molecules of ammonia combine with another waste product, carbon dioxide, to form **urea**. Urea is 100 000 times less toxic than ammonia. The blood can dissolve 33 mg of urea per 100 mL of blood. A second waste product, **uric acid**, is formed by the breakdown of nucleic acids. **Table 1** summarizes the roles of various organs in the removal of metabolic waste.

The kidneys help maintain water balance. Although it is possible to survive for weeks without food, humans cannot survive for more than a few days without water. Humans deplete their water reserves faster than their food reserves. The average adult loses about 2 L of water every day through urine, perspiration, and exhaled air. Greater volumes are lost when physical activity increases. For the body to maintain water balance, humans must consume 2 L of fluids daily. A drop in fluid intake by as little as 1 % of your body mass will cause thirst, a decrease of 5 % will bring about extreme pain and collapse, while a decrease of 10 % will cause death.

**deamination** removal of an amino group from an organic compound

**urea** nitrogen waste formed from two molecules of ammonia and one molecule of carbon dioxide

**uric acid** a waste product formed from the breakdown of nucleic acids

## EXTENSION

**Water and Solute Balance**
This animation discusses the processes that influence water and solute balance in mammals.

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**Table 1** Removal of Metabolic Waste

| Waste product | Origin | Organ of excretion |
|---|---|---|
| ammonia | • deamination of amino acids by the liver | kidneys |
| urea | • deamination of amino acids by the liver<br>• ammonia combined with carbon dioxide | kidneys; skin (small amounts) |
| uric acid | • product of the breakdown of nucleic acids, such as DNA | kidneys |
| carbon dioxide | • waste product of cellular respiration | lungs |
| bile pigments | • breakdown of red blood cell pigment hemoglobin | liver |
| lactic acid | • product of anaerobic respiration | liver |

## DID YOU KNOW?

**Uric Acid**
Uric acid is found in the urine of only a few mammals: humans, higher apes, and Dalmatian dogs. The uric acid molecule has a structure similar to that of caffeine.

## Anatomy of the Urinary System

Renal arteries branch from the abdominal aorta and carry blood to the kidneys. With a mass of about 0.5 kg each, the fist-shaped kidneys may hold as much as 25 % of the body's blood at any given time. **Figure 2** shows the position of the kidneys and other organs of the urinary system in the body. Wastes are filtered from the blood by the kidneys and conducted to the urinary bladder by **ureters**. A urinary sphincter muscle located at the base of the bladder acts as a valve, permitting the storage of urine. When approximately 200 mL of urine has been collected, the bladder stretches slightly and nerves send a signal to the brain. When the bladder fills to about 400 mL, more stretch receptors are activated and the message becomes more urgent. If a person continues to ignore the messages, the bladder continues to fill. After about 600 mL of urine has accumulated, voluntary control is lost. The sphincter relaxes, urine enters the **urethra**, and it is voided.

The cross section of the kidney in **Figure 2** reveals three structures. An outer layer of connective tissue, the **cortex**, encircles the kidney. An inner layer, the **medulla**, is found beneath the cortex. A hollow chamber, the **renal pelvis**, joins the kidney with the ureter.

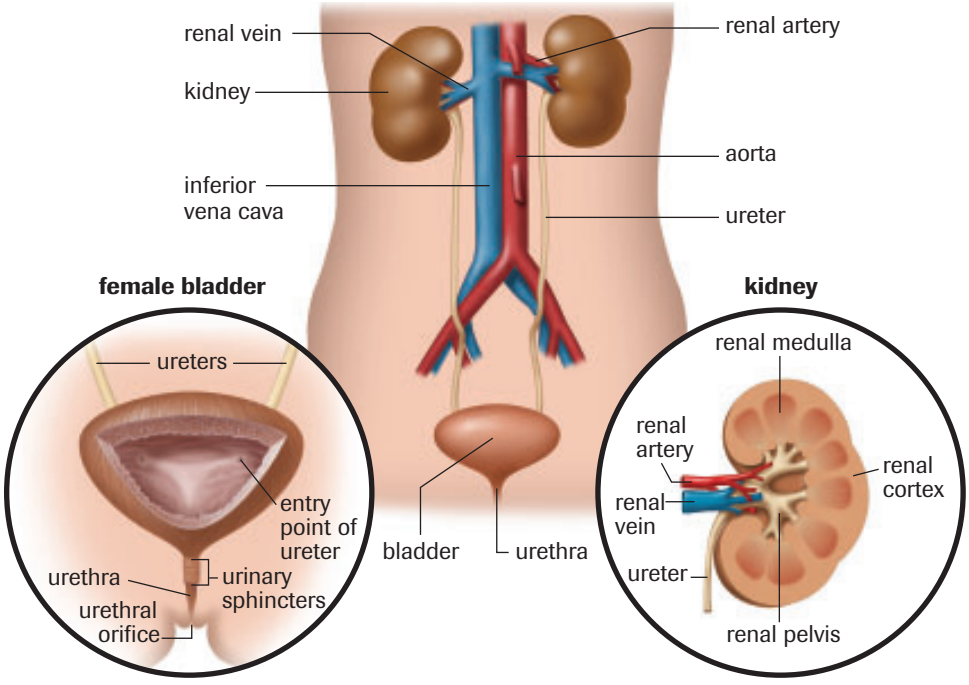



**Figure 2**
The human urinary system

**ureter** a tube that conducts urine from the kidney to the bladder

**urethra** the tube that carries urine from the bladder to the exterior of the body

**cortex** the outer layer of the kidney

**medulla** the area inside of the cortex

**renal pelvis** the hollow area where the kidney joins the ureter

### Nephrons

Approximately one million slender tubules, called **nephrons**, are the functional units of the kidneys (**Figure 3**, next page). Small branches from the renal artery, the **afferent arterioles**, supply the nephrons with blood. The afferent arterioles branch into a capillary bed, called the **glomerulus**. Unlike other capillaries, the glomerulus does not transfer blood to a venule. Blood leaves the glomerulus by way of other arterioles, the **efferent arterioles**. Blood is carried from the efferent arterioles to a net of capillaries called **peritubular capillaries** that wrap around the kidney tubule. Blood leaves the nephron via a venule that joins the renal vein.

**nephron** a functional unit of the kidney

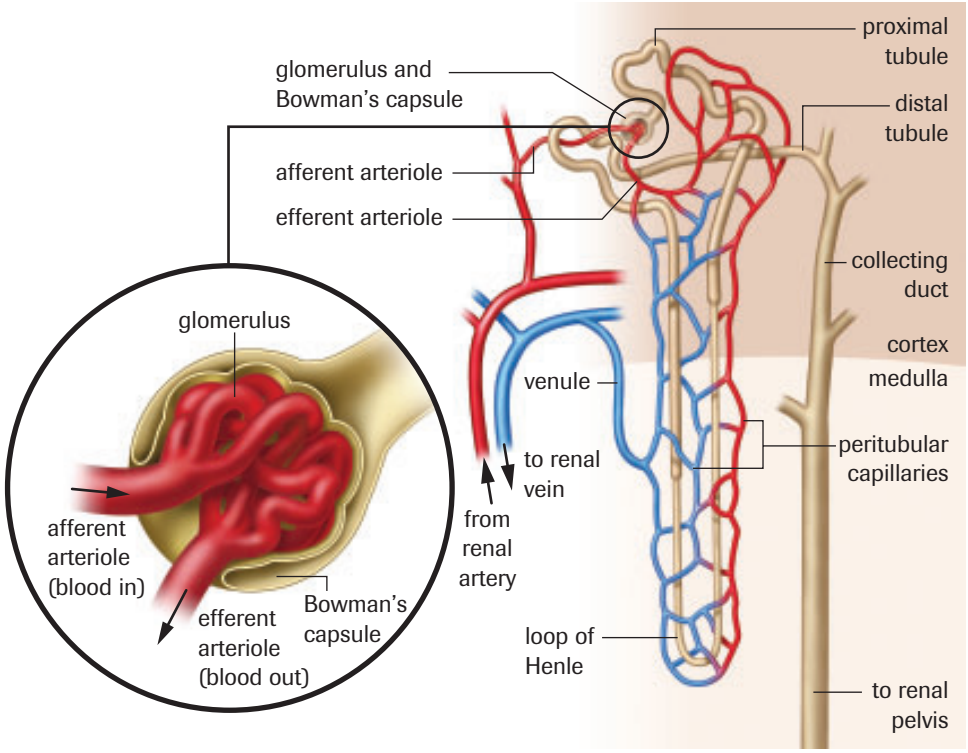
**afferent arteriole** a small branch of the renal artery that carries blood to the glomerulus

**glomerulus** the high-pressure capillary bed that is the site of filtration

**efferent arteriole** a small branch of the renal artery that carries blood away from the glomerulus to the peritubular capillaries

**peritubular capillary** a member of the network of small blood vessels that surround the tubule of the nephron

**Figure 3**
Diagram of a nephron showing the glomerulus and Bowman's capsule




**Bowman's capsule** the cuplike structure that surrounds the glomerulus

**proximal tubule** the section of the nephron joining the Bowman's capsule with the loop of Henle

**loop of Henle** the section of the tubule that carries filtrate from the proximal tubule to the distal tubule

**distal tubule** conducts urine from the loop of Henle to the collecting duct

**collecting duct** a tube that carries urine from nephrons to the renal pelvis

The glomerulus is surrounded by a funnel-like part of the nephron called the **Bowman's capsule**. The Bowman's capsule, the afferent arteriole, and the efferent arteriole are located in the cortex of the kidney. Fluid to be processed into urine enters the Bowman's capsule from the blood. The capsule tapers to a thin tubule, called the **proximal tubule**. Urine is carried from the proximal tubule to the **loop of Henle**, which descends into the medulla of the kidney. Urine moves through the **distal tubule**, the last segment of the nephron, into the **collecting ducts**. As the name suggests, the collecting ducts collect urine from many nephrons that, in turn, merge in the pelvis of the kidney.

### Practice

1. Describe the two main functions of the kidneys.
2. What is deamination and why is it an important process?
3. How does the formation of urea prevent poisoning?

## Formation of Urine

Urine formation depends on three functions. Filtration is accomplished by the movement of fluid from the blood into the Bowman's capsule. Reabsorption involves the transfer of essential solutes and water from the nephron back into the blood. Secretion involves the transport of materials from the blood into the nephron.

### Filtration

Each nephron of the kidney has an independent blood supply. Blood moves through the afferent arteriole into the glomerulus, a high-pressure filter. Normally, pressure in a capillary bed is about 25 mmHg. The pressure in the glomerulus is about 65 mmHg.

### EXTENSION

**Structure of the Glomerulus**
This animation provides a closer look at the structure of the glomerulus, and its role in urine formation (filtration).

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Dissolved solutes pass through the walls of the glomerulus into the Bowman's capsule. Although materials move from areas of high pressure to areas of low pressure, not all materials enter the capsule. Scientists have extracted fluid from the glomerulus and Bowman's capsule using a thin glass tube called a micropipette. **Table 2** compares sample solutes extracted from the glomerulus and Bowman's capsule.

Plasma protein, blood cells, and platelets are too large to move through the walls of the glomerulus. Smaller molecules pass through the cell membranes and enter the nephron.

**Table 2** Comparison of Solutes

| Solute | Glomerulus | Bowman's capsule |
|---|---|---|
| water | yes | yes |
| sodium chloride | yes | yes |
| glucose | yes | yes |
| amino acids | yes | yes |
| hydrogen ions | yes | yes |
| urea | yes | yes |
| plasma proteins | yes | no |
| erythrocytes | yes | no |
| platelets | yes | no |

## Reabsorption

On average, about 600 mL of fluid flows through the kidneys every minute. Approximately 20 % of the fluid, or about 120 mL, is filtered into the nephrons. Imagine what would happen if none of the filtrate were reabsorbed back into the blood. You would form 120 mL of urine each minute. You would also have to consume at least 1 L of fluid every 10 min to maintain equilibrium. Much of your day would be concerned with regulating water balance. Fortunately, only 1 mL of urine is formed for every 120 mL of fluid filtered into the nephron. The remaining 119 mL of fluid and solutes is reabsorbed. Aldosterone is a hormone that increases the reabsorption of $Na^+$ ions and water by the kidneys, thereby helping to maintain body fluid levels.

Selective reabsorption occurs by both active and passive transport. Carrier molecules move $Na^+$ ions across the cell membranes of the cells that line the nephron. Negative ions, such as $Cl^-$ and $HCO_3^-$, follow the positive $Na^+$ ions by charge attraction (**Figure 4** on next page). Numerous mitochondria supply the energy necessary for active transport. However, the energy supply is limited. Reabsorption occurs until the **threshold level** of a substance is reached. Excess NaCl remains in the nephron and is excreted with the urine.

Other molecules are actively transported from the proximal tubule. Glucose and amino acids attach to specific carrier molecules, which shuttle them out of the nephron and into the blood. However, the amount of solute that can be reabsorbed is limited. For example, excess glucose will not be shuttled out of the nephron by the carrier molecules. This means that individuals with high blood glucose and those who consume large amounts of simple sugars will excrete only some of the excess glucose.

The solutes that are actively transported out of the nephron create an osmotic gradient that draws water from the nephron. A second osmotic force, created by the proteins not filtered into the nephron, also helps reabsorption. The proteins remain in the bloodstream and draw water from the **interstitial fluid** into the blood. As water is reabsorbed from the nephron, the remaining solutes become more concentrated. Molecules such as urea and uric acid will diffuse from the nephron back into the blood, although less is reabsorbed than was originally filtered.

**EXTENSION**

**Kidney Filtration and Exercise**

This Audio Clip will explore the factors that contribute to lower levels of kidney filtration during exercise and relate these factors to the changes in blood chemistry during exercise.

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**CAREER CONNECTION**

**Urologist**

Urology is a medical specialty that deals with the urinary system. What types of things do urologists do? Do they ever perform kidney transplants? Find out what training is needed to become a urologist.

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**threshold level** the maximum amount of a substance that can be moved across the nephron

**EXTENSION**

**Tubular Reabsorption**

This animation illustrates how solutes and water are reabsorbed from the nephron back into the blood.

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**interstitial fluid** the fluid that surrounds the body cells

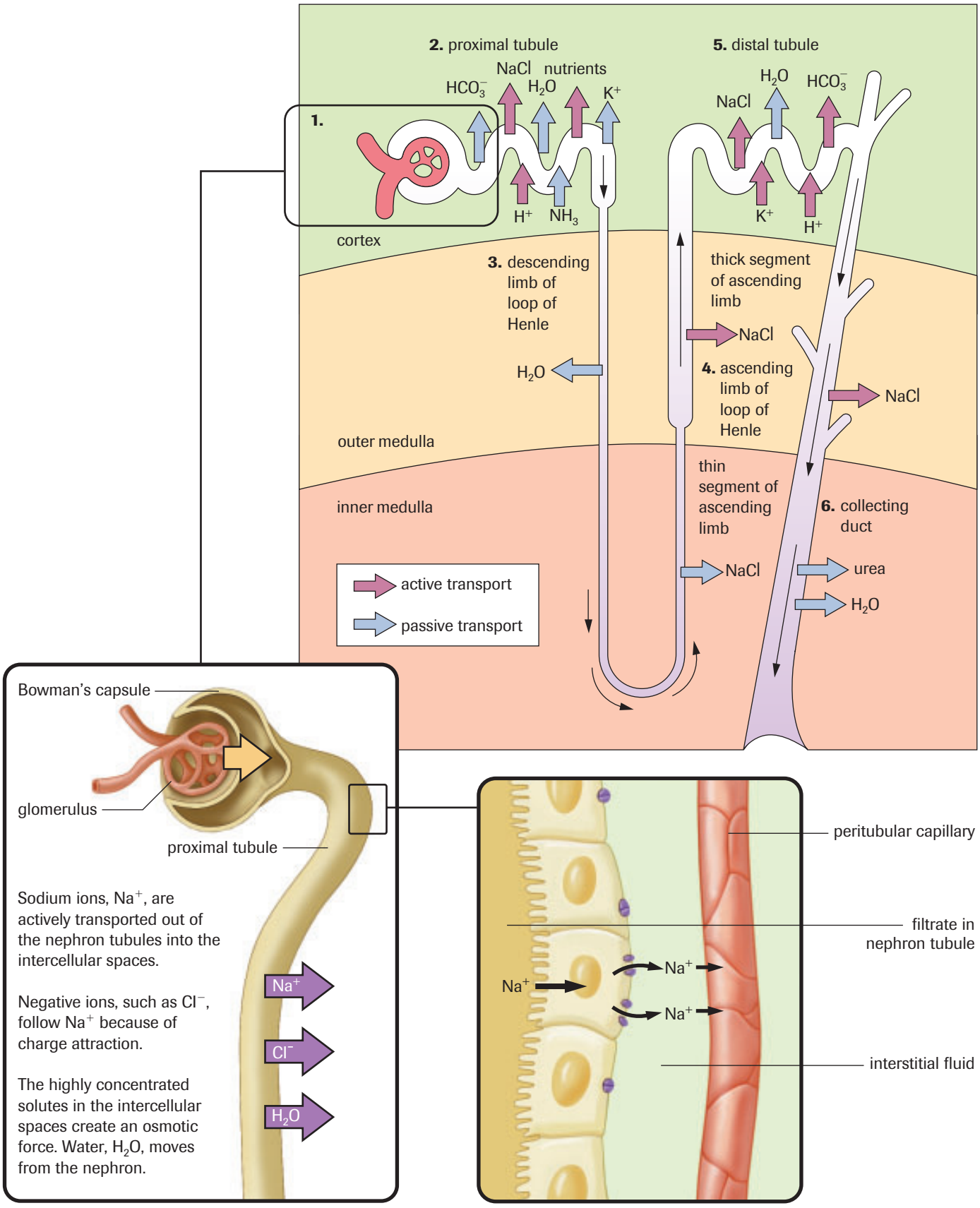


**Figure 4**

Overview of the steps in urine formation. The numbers in the diagram match the processes in **Table 3**, on the next page.

## Secretion

Secretion is the movement of substances from the blood into the nephron. Ammonia, excess $H^+$ ions, and minerals such as $K^+$ ions are examples of substances secreted. Even drugs such as penicillin can be secreted. Cells loaded with mitochondria line the distal tubule. As in reabsorption, tubular secretion occurs by active transport, but, unlike in reabsorption, molecules are shuttled from the blood into the nephron. **Table 3** summarizes the events in urine formation.

**Table 3** Urine Formation

| Site | Description of process | Substances transported |
|---|---|---|
| **1.** glomerulus and Bowman's capsule | • Filtration of water and dissolved solutes occurs as blood is forced through walls of glomerulus into Bowman's capsule by fluid pressure in capillaries. | • sodium ions ($Na^+$), chloride ions ($Cl^-$), water ($H_2O$), hydrogen ions ($H^+$), glucose, amino acids, vitamins, minerals, urea, uric acid |
| **2.** proximal tubule | • Selective reabsorption of nutrients from filtrate back into blood occurs by active and passive transport.<br>• Within proximal tubule, pH is controlled by secretion of hydrogen ions ($H^+$) and reabsorption of bicarbonate ions ($HCO_3^-$). | • bicarbonate ions ($HCO_3^-$), salt (NaCl), water ($H_2O$), potassium ions ($K^+$), hydrogen ions ($H^+$), ammonia ($NH_3$), glucose, amino acids, vitamins, urea |
| **3.** descending limb of loop of Henle | • The descending limb of loop of Henle is permeable to water, resulting in loss of water from the filtrate by osmosis.<br>• Salt (NaCl) becomes concentrated in the filtrate as descending limb penetrates inner medulla of kidney. | • water ($H_2O$) |
| **4.** ascending limb of loop of Henle | • A thin segment of ascending limb of loop of Henle is permeable to salt, resulting in the diffusion of salt out of ascending limb.<br>• Salt continues to pass from filtrate to interstitial fluid in the thick segment of ascending limb. | • salt (NaCl) |
| **5.** distal tubule | • Secretion of substances from blood into nephron occurs by active transport. Distal tubule helps regulate potassium ($K^+$) and salt (NaCl) concentration of body fluids.<br>• As in the proximal tubule, pH is controlled by tubular secretion of hydrogen ions ($H^+$) and reabsorption of bicarbonate ions ($HCO_3^-$). | • salt (NaCl), potassium ions ($K^+$), water ($H_2O$), hydrogen ions ($H^+$), bicarbonate ions ($HCO_3^-$), uric acid, ammonia ($NH_3$) |
| **6.** collecting duct | • Urine formation | • water ($H_2O$), salt (NaCl), urea, uric acid, minerals |

### Practice

**4.** State the function of each part of the nephron: Bowman's capsule, proximal tubule, loop of Henle, distal tubule, and collecting duct.

**5.** Describe the three main processes that are involved in urine formation.

## LAB EXERCISE 12.A

**Report Checklist**

| | | |
|---|---|---|
| ○ Purpose | ○ Design | ● Analysis |
| ○ Problem | ○ Materials | ○ Evaluation |
| ○ Hypothesis | ○ Procedure | ○ Synthesis |
| ○ Prediction | ○ Evidence | |

### *Comparing Solutes in the Plasma, Nephron, and Urine*

Micropipettes were used to draw fluid from the Bowman's capsule, the glomerulus, the loop of Henle, and the collecting duct. Solutes in the fluids were measured. The resulting data are displayed in **Table 4**.

### Analysis

(a) Which of the solutes was not filtered into the nephron? Explain your answer.

(b) The test for glucose was not completed for the sample taken from the glomerulus. Predict whether glucose would be found in the glomerulus. Provide reasons for your prediction.

(c) Why do urea and ammonia levels increase after filtration occurs?

(d) Chloride ions, $Cl^-$, follow actively transported $Na^+$ ions from the nephron into the blood. Therefore, you would expect the $Cl^-$ concentration to decrease as fluids are extracted along the nephron. What causes the discrepancy?

(e) Is it correct to say that veins carry blood with high concentrations of waste products and arteries carry blood with high concentrations of nutrients? Explain.

(f) Compare the blood found in a renal artery and a renal vein with respect to urea and glucose.

**Table 4** Solute Concentrations in Various Parts of the Kidney

| Solute | Bowman's capsule | Glomerulus | Loop of Henle | Collecting duct |
|---|---|---|---|---|
| protein | 0 | 0.8 | 0 | 0 |
| urea | 0.05 | 0.05 | 1.50 | 2.00 |
| glucose | 0.10 | no data | 0 | 0 |
| chloride ions | 0.37 | no data | no data | 0.6 |
| ammonia | 0.0001 | 0.0001 | 0.0001 | 0.04 |
| substance X | 0 | 9.15 | 0 | 0 |

Quantities are in g/100 mL.

**WEB Activity**

### *Simulation—Kidney Function*

In this activity, you can follow the links to a number of computer-generated simulations of kidney function. Trace the pathway of fluid through the different parts of the kidney. You can also find other diagrams and descriptions of kidney function. Research and create a flow chart to show how the excretory system maintains water and ions in equilibrium.

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## INVESTIGATION 12.1 *Introduction*

**Report Checklist**

| | | |
|---|---|---|
| ○ Purpose | ● Design | ● Analysis |
| ● Problem | ● Materials | ● Evaluation |
| ● Hypothesis | ● Procedure | ○ Synthesis |
| ● Prediction | ● Evidence | |

### *Do Sports Drinks Really Work?*

Are sports drinks any better than water and sugar? How can you determine whether a sports drink is able to restore the electrolytes essential for the operation of nerves and muscles?

*To perform this investigation, turn to page 393.*

## pH Balance

In addition to regulating body fluid volumes and maintaining the composition of salts in the blood, the kidneys maintain pH balance. Despite the variety of foods and fluids consumed with varying pH levels, the pH of the body remains relatively constant, between 7.3 and 7.5. In addition, during cellular respiration, cells produce carbon dioxide, which forms carbonic acid. Carbonic acid and other excess acids ionize to produce $H^+$ ions. The buildup of $H^+$ ions lowers pH.

An acid–base balance is maintained by buffer systems that absorb excess $H^+$ ions or ions that act as bases. Excess $H^+$ ions from metabolic processes are buffered by bicarbonate ions in the blood. Bicarbonate ions, $HCO_3^-$, eliminate the excess $H^+$ ions, preventing a change in pH. Carbonic acid, a weak acid, is produced. In turn, the carbonic acid breaks down to form carbon dioxide and water. The carbon dioxide is then transported to the lungs where much of it is exhaled. The following reaction shows one type of buffer system, called the bicarbonate–carbon dioxide buffer system (**Figure 5**):

$$HCO_3^- + H^+ \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons H_2O + CO_2$$

The buffer system of the blood removes excess $H^+$ ions; however, the buffer must be restored if the body is to be protected. The kidneys help restore the buffer by reversing the reaction. As shown in **Figure 5**, carbon dioxide is actively transported from the peritubular capillaries, which surround the nephron, into the cells that line the nephron. The carbon dioxide combines with water to initiate the reverse reaction, generating $HCO_3^-$ and $H^+$ ions. The bicarbonate ions diffuse back into the blood, thereby restoring the buffer. The $H^+$ ions recombine with either phosphate ions or ammonia and are excreted with the filtrate from the nephron.

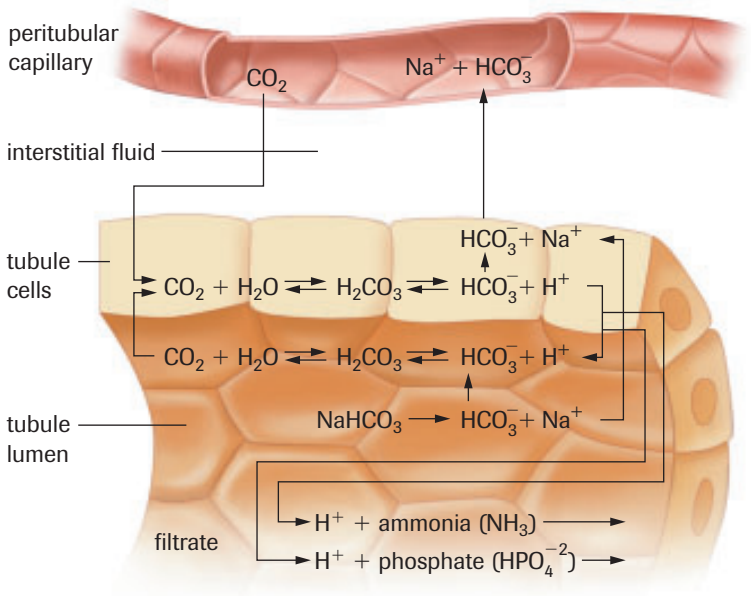


**Figure 5**
The bicarbonate–carbon dioxide buffer system maintains the pH balance.

**CAREER CONNECTION**

**Emergency Medical Technician**

Emergency medical technicians (EMTs), or paramedics, deliver pre-hospital emergency care. Their responsibilities include cardiopulmonary resuscitation, monitoring vital signs, starting intravenous lines, administering drugs, assisting in childbirth, and immobilizing patients. Discover more about the technical training programs EMTs receive.

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## SUMMARY Waste Excretion and Internal Equilibrium

- The kidneys filter waste from the blood and help maintain water balance.
- The liver helps to eliminate toxic nitrogen groups from the body by deamination.
- Nephrons are the functional units of the kidneys.
- Urine formation depends on three functions: filtration, reabsorption, and secretion.
- The glomerulus acts as a high-pressure filter.
- Selective reabsorption occurs by both active and passive transport.
- Secretion is the active transport of waste from the blood into the nephron.
- Kidneys help maintain pH by excreting excess $H^+$ ions and restoring $HCO_3^-$ ions to the blood.

**Table 5** Summary of Nephron Structure and Function

| Structure | Function |
|---|---|
| afferent arteriole | carries blood to the glomerulus |
| glomerulus | a high-pressure capillary bed enclosed by the Bowman's capsule that is the site of filtration |
| efferent arteriole | carries blood away from the glomerulus |
| peritubular capillary bed | capillaries that network around the nephron |
| venule | carries filtered blood out of the nephron |

## Section 12.1 Questions

1. Why do you think it is beneficial to humans to have two kidneys rather than one? Explain your answer.
2. Explain the function of nephrons.
3. Use the diagram in **Figure 6** to identify the following:
   (a) the structure that filters blood
   (b) the structure that carries urine from the kidney
   (c) the structure that carries blood containing urea into the kidney
   (d) the structure that stores urine

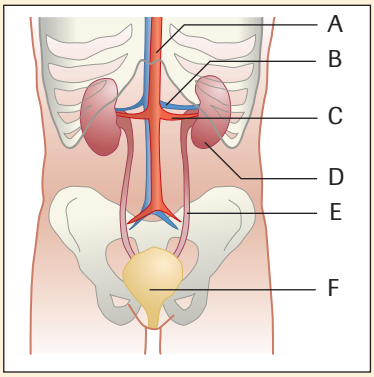


**Figure 6**

4. An adult under normal conditions will eliminate about 1.5 L of urine daily. Design an experiment that will test how urine output is affected by the consumption of a food containing caffeine (e.g., coffee, tea, chocolate, cola).
5. Explain why individuals who consume large amounts of sugars might do the following:
   (a) excrete large amounts of glucose in the urine
   (b) excrete large amounts of urine
6. Marine fish, such as herring and cod, live in a hypertonic environment. These fish lose water through their gills by osmosis. To replace the water, the fish drink seawater.
   (a) Explain why these fish must actively transport salt from their bodies.
   (b) Because these fish excrete salt through their gills, kidney function is affected. Explain the effect on the volume of urine excreted and the concentration of solutes in the urine.
7. Explain why the regulation of salt is important for people with renal hypertension.
8. What role do the kidneys serve in maintaining pH?
9. Using the $HCO_3^-$ buffering system, explain what would happen if the kidneys failed to excrete $H^+$ ions.
10. Using the Internet and other resources, conduct research to explain how urine might be recycled on a space flight.

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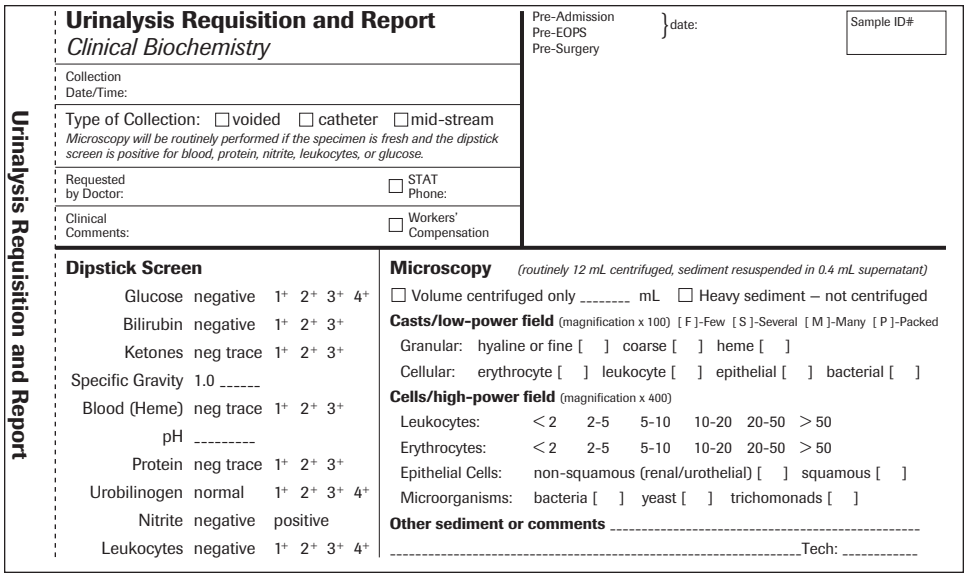
# Kidney Dysfunction 12.2

Proper functioning of the kidneys is essential for the body to maintain equilibrium. The multifunctional kidneys are affected when other systems break down; conversely, kidney dysfunction affects other systems. Many kidney disorders can be detected by urinalysis (**Figure 1**).



**Urinalysis Requisition and Report**

*Clinical Biochemistry*

Collection Date/Time:

Type of Collection: ☐ voided ☐ catheter ☐ mid-stream

*Microscopy will be routinely performed if the specimen is fresh and the dipstick screen is positive for blood, protein, nitrite, leukocytes, or glucose.*

Requested by Doctor: ☐ STAT Phone:

Clinical Comments: ☐ Workers' Compensation

Pre-Admission
Pre-EOPS
Pre-Surgery
} date:

Sample ID#

**Dipstick Screen**

| | | |
|---|---|---|
| Glucose | negative | 1+ 2+ 3+ 4+ |
| Bilirubin | negative | 1+ 2+ 3+ |
| Ketones | neg trace | 1+ 2+ 3+ |
| Specific Gravity | 1.0 ____ | |
| Blood (Heme) | neg trace | 1+ 2+ 3+ |
| pH | ---------- | |
| Protein | neg trace | 1+ 2+ 3+ |
| Urobilinogen | normal | 1+ 2+ 3+ 4+ |
| Nitrite | negative | positive |
| Leukocytes | negative | 1+ 2+ 3+ 4+ |

**Microscopy** *(routinely 12 mL centrifuged, sediment resuspended in 0.4 mL supernatant)*

☐ Volume centrifuged only _____ mL ☐ Heavy sediment – not centrifuged

**Casts/low-power field** (magnification x 100) [ F ]-Few [ S ]-Several [ M ]-Many [ P ]-Packed

Granular: hyaline or fine [ ] coarse [ ] heme [ ]

Cellular: erythrocyte [ ] leukocyte [ ] epithelial [ ] bacterial [ ]

**Cells/high-power field** (magnification x 400)

| | | | | | | |
|---|---|---|---|---|---|---|
| Leukocytes: | < 2 | 2-5 | 5-10 | 10-20 | 20-50 | > 50 |
| Erythrocytes: | < 2 | 2-5 | 5-10 | 10-20 | 20-50 | > 50 |

Epithelial Cells: non-squamous (renal/urothelial) [ ] squamous [ ]

Microorganisms: bacteria [ ] yeast [ ] trichomonads [ ]

**Other sediment or comments** _____

_____Tech: _____

**Figure 1**
Many kidney problems can be diagnosed by analyzing a urine sample.

## Diabetes Mellitus

Diabetes mellitus is caused by inadequate secretion of insulin from islet cells in the pancreas. Without insulin, blood glucose levels tend to rise. Some people with diabetes mellitus need insulin injections to regulate their blood glucose levels. The cells of the proximal tubule are supplied with enough ATP to reabsorb 0.1 % blood glucose, but in diabetes mellitus much higher blood glucose concentrations are found. The excess glucose remains in the nephron and is excreted in the urine. This excess glucose provides an osmotic pressure that opposes the osmotic pressure created by other solutes that have been actively transported out of the nephron. Water remains in the nephron and is lost with the urine. Individuals with untreated diabetes mellitus void large volumes of urine, which explains why they are often thirsty. The water lost with the excreted sugar must be replenished.

Another form of diabetes, diabetes insipidus, results from a defect in a different hormone—antidiuretic hormone (ADH), which regulates water reabsorption in the nephron. A person with this form of diabetes produces large volumes of dilute urine.

**EXTENSION**

**Osmoregulation in the Collecting Duct**

This Audio Clip examines how antidiuretic hormone (ADH) impacts the cells of the collecting duct in the kidney and influences the amount of water that is re-absorbed from the filtrate.

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## Nephritis

Nephritis is not a single disease but a broad description of many diseases characterized by inflammation of the nephrons. One type of nephritis affects the tiny blood vessels of the glomerulus. It is believed that toxins produced by invading microbes destroy the tiny blood vessels, altering the permeability of the nephron. Proteins and other large molecules are able to pass into the nephron. Because no mechanism is designed to reabsorb protein, the proteins remain in the nephron and create an osmotic pressure that draws water into the nephron. The movement of water into the nephron increases the output of urine. Nephritis can lead to irreversible kidney damage and kidney failure.

**Figure 2**
This kidney contains several large stones. Most stones consist mainly of calcium oxalate, calcium phosphate, or both.

## Kidney Stones

Kidney stones (**Figure 2**) are caused by the precipitation of mineral solutes from the blood. The sharp-sided stones can lodge in the renal pelvis, or they may move down the ureter into the bladder and be passed out of the body with the urine. Delicate tissues are torn as the stone moves toward the bladder, causing excruciating pain. Larger stones may even lodge in the ureter, which requires medical attention.

### Blasting Kidney Stones

The traditional treatment for unpassable kidney stones has been surgical removal followed by a period of convalescence. A technique developed by German urologist Dr. Christian Chaussy, called extracorporeal shock-wave lithotripsy (ESWL), has greatly improved prospects for kidney stone patients with stones less than 2 cm in size.

The nonsurgical technique uses high-energy shock waves to break the kidney stones into small fragments. The shock waves pass through soft tissue and strike the stone. After a few days, tiny granules from the stone can be voided through the excretory system.

Not all stones can be eliminated by shock-wave treatment. The size of the stone, its location in the urinary tract, and its composition all determine whether ESWL is an appropriate treatment. In most cases, this technique can be performed on an outpatient basis, and recovery time is greatly reduced from that of surgical removal.

**INVESTIGATION 12.2** ***Introduction***

### *Diagnosis of Kidney Disorders*

How is urinalysis used to detect various kidney disorders? In this investigation, you will test simulated urine for kidney disease.

**Report Checklist**

| | | |
|---|---|---|
| ○ Purpose | ● Design | ● Analysis |
| ● Problem | ○ Materials | ● Evaluation |
| ● Hypothesis | ○ Procedure | ● Synthesis |
| ● Prediction | ● Evidence | |

***To perform this investigation, turn to page 394.***

## Dialysis Technology

For people whose kidneys cannot effectively process bodily wastes, a dialysis machine can restore the proper solute balance. Dialysis is defined as the exchange of substances across a semipermeable membrane. Like a kidney that is functioning normally, a dialysis machine operates on the principles of diffusion and blood pressure. However, unlike a kidney, a dialysis machine cannot perform active transport.

There are two types of dialysis: hemodialysis and peritoneal dialysis (**Figure 3**, next page). In hemodialysis, the machine is connected to the patient's circulatory system by a vein. Blood is pumped through a series of dialysis tubes that are submerged in a bath of various solutes. Glucose and a mixture of salts set up concentration gradients. For example, $HCO_3^-$ ions will move from the bath into the blood if it is too acidic. Because the dialysis fluids have no urea, this solute always moves from the blood into the dialysis fluid. Urea will move from the blood into the dialysis fluid until equal concentrations are established. By continually flushing expended dialysis solution and replacing it, the process continually removes urea and other waste solutes. During hemodialysis, the body also receives the hormones the kidneys are unable to produce.

An alternative is peritoneal dialysis, sometimes referred to as continuous ambulatory peritoneal dialysis (CAPD). With this method, 2 L of dialysis fluid is pumped into the abdominal cavity, and the membranes of the cavity selectively filter wastes from the blood. Urea and other wastes diffuse from the plasma into the peritoneum and into the dialysis fluid. Wastes accumulate in the dialysis fluid, which can be drained off and

***DID YOU KNOW?***

**Earliest Treatment of Kidney Stones**

Operations to remove kidney stones were performed in the time of Hippocrates, the Greek physician considered to be the father of medicine (c. 460–377 B.C.E.).

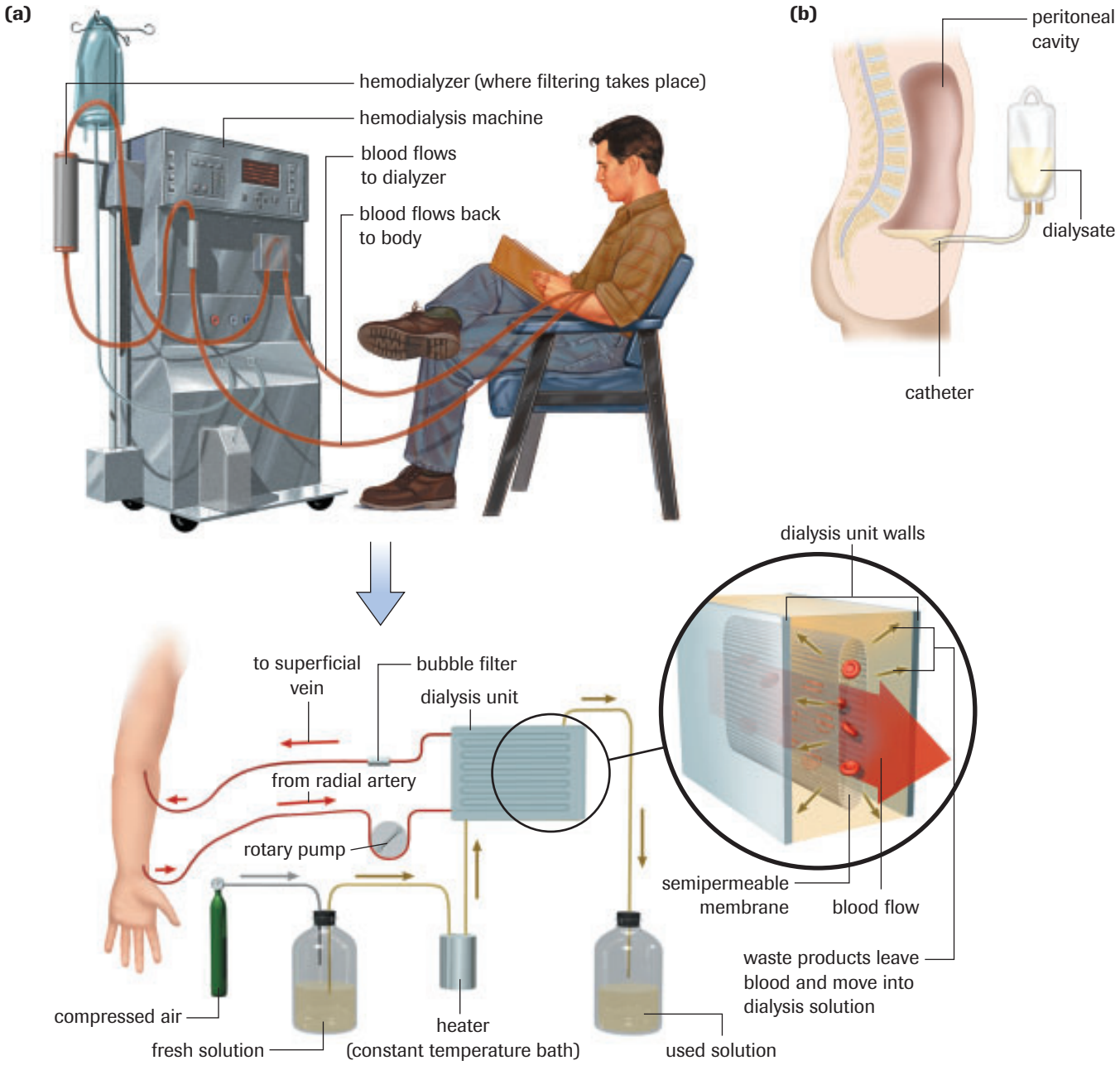


**Figure 3**

**(a)** In hemodialysis, a unit called a dialyzer mimics the action of the nephron. For hemodialysis treatments, a person must first have a minor surgical procedure to create an access, a shunt, for the needles and tubing needed to connect the circulatory system to the dialysis machine. Most people need three weekly dialysis sessions of about four hours each.

**(b)** Peritoneal dialysis is done through the peritoneal membrane, which is the lining of the abdominal cavity. In a minor surgical procedure, a catheter (a thin tube) is first inserted. A solution called the dialysate is then fed into the abdominal cavity through the catheter. The dialysate remains in this cavity for two to six hours. Then, the dialysate fluid is drained from the abdomen via the catheter. Once the fluid is drained, new fluid is placed to begin the process anew.

**EXTENSION**

**Kidney Dialysis**

This animation explains in more detail how hemodialysis and peritoneal dialysis work to restore proper solute balance in place of functioning kidneys.

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replaced several times a day. As dialysis occurs, the patient may continue with non-strenuous activities. Peritoneal dialysis allows for greater independence because patients can perform the procedure in their own home.

Although dialysis technology can remove toxic wastes from the body and maintain electrolyte balance, it is unable to accomplish other tasks of the kidneys. Dialysis equipment is not able to produce hormones, such as erythropoietin and renin, nor is it able to activate vitamin D.

A new and promising technique involves the transplant of kidney cells from a pig into a dialysis machine. The living cells not only produce renal hormones but seem to be much better at regulating electrolytes and pH.

## Kidney Transplants

According to the Kidney Foundation of Canada, a patient diagnosed with end-stage renal disease (kidney failure) in the 1960s had little chance of surviving. By the 1970s, renal dialysis had changed life expectancy dramatically, but the patient had to spend up to 36 hours each week in treatment. By the 1980s, hemodialysis had reduced treatments to 12 hours a week.

Although dialysis machines are effective, nothing can surpass the workings of a real kidney. Today, kidney transplants are 85 % successful and the preferred treatment for many patients (**Figure 4**). A transplanted kidney produces hormones and responds to the homeostatic adjustments of other body systems. The main disadvantage with any transplant is the immune response of the recipient. The donor kidney is often identified as a foreign invader, and the recipient's immune system springs into action in an attempt to destroy it. (See "Recognizing Harmful Antigens," Section 11.2, page 364.)

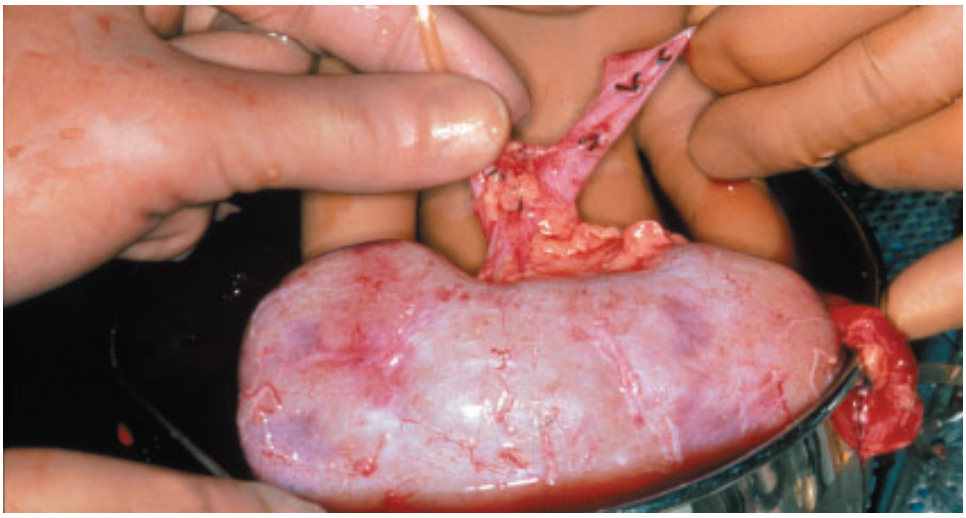

**Figure 4**
A human kidney being prepared for transplant

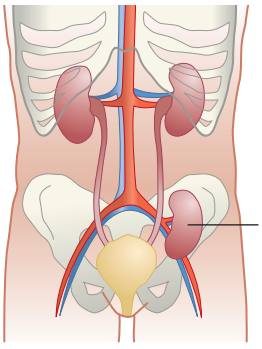


**Figure 5**
Location of new kidney

A kidney transplant involves placing a new kidney and ureter in the lower abdomen near the groin, where they are surgically attached to the blood vessels and bladder (**Figure 5**). The operation usually takes two to four hours. The old kidneys are not usually removed unless they are very large or chronically infected. After surgery, a catheter is inserted into the bladder for several days to drain the urine produced by the new kidney. Sometimes dialysis is required after the transplant until the new kidney can fully function. Immunosuppresive drugs are given after the transplant to help prevent rejection of the new organ.

## EXPLORE an issue

**Issue Checklist**

| | | |
|---|---|---|
| ○ Issue | ○ Design | ● Analysis |
| ● Resolution | ● Evidence | ● Evaluation |

# Xenotransplants

A survey of Canadians in the year 2000 found that

- 94 % agreed that organ donation was a positive outcome of a person's death;
- 81 % indicated a willingness to donate organs; and
- 65 % reported having had a discussion about organ donation with loved ones.

In spite of public education, the organ donation rate in Canada is less than 40 %. The shortage of organs has spurred scientists to explore new and creative solutions for the many patients awaiting new organs. Xenotransplants are transplants from one species to another (*xeno* means strange or foreign). Xenotransplants from animals to humans have been attempted for several decades, but scientists have yet to successfully solve the problem of organ rejection. Improvements in immunosuppressive drugs have extended the boundaries of possibility and could relieve the wait for thousands of patients.

A second advance, the placement of human genes into animals by genetic engineering, has made xenotransplantation even more viable. Transgenic animals are animals that have genes from other species inserted into their DNA. Because transgenic animals possess not only their own genes but also those of humans, the chances of rejection are reduced. The immune system of the recipient will recognize the human marker on cell membranes as being related to their own tissues.

Although primates were once used as the primary source for xenotransplants, pigs have become the most common animal (**Figure 6**). The organs of the pig resemble those of humans in both size and structure. In addition, pigs are easier and less expensive to breed. Baboons, the early primate of choice, were found to harbour many viruses that can easily be transferred to humans.

As of 2003, xenotransplants were not allowed in Canada. One of the fears is the introduction of new viruses into humans. Microbes that might be harmless in their natural animal host could be deadly in a human. Could xenotransplants cause an outbreak of a deadly disease?

**Figure 6**
Pigs have become the animal of choice for xenotransplants.

**Statement**
The government should allow xenotransplants in Canada.

(a) In your group, research the issue. Search for information in newspapers, periodicals, CD-ROMs, and the Internet.

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(b) Discuss the issue with class members and others in preparation for the debate.

(c) Write a list of points and counterpoints that your group considered.

(d) Decide whether your group agrees or disagrees with the statement.

(e) Prepare to defend your group's position in a class discussion.

(f) What responsibilities do governments have to ensure that all groups have a voice in the debate?

## SUMMARY Kidney Dysfunction

- Proper functioning of the kidneys is essential for maintaining equilibrium.
- Many kidney diseases can be detected by urinalysis.
- A number of kidney diseases affect proper kidney function, including diabetes mellitus, diabetes insipidus, nephritis, and kidney stones.
- Dialysis and transplants are the most common treatments for kidney disease.

## Section 12.2 Questions

1. What are kidney stones?
2. Explain why people with diabetes become dehydrated.
3. Why isn't there a cure for nephritis?
4. Sketch a diagram of a kidney dialysis machine and explain how it works.
5. Identify advantages of peritoneal dialysis over hemodialysis.
6. Complete **Table 1** in your notebook.

**Table 1** Types of Kidney Dysfunction

| Kidney dysfunction | Cause | Problem created | Recommended treatment |
|---|---|---|---|
| diabetes mellitus | lack of insulin production | glucose in urine will cause dehydration | |
| diabetes insipidus | | | ADH provided by injection |
| nephritis | | | |
| kidney stones | | | |

7. What is the most difficult challenge to overcome in achieving successful kidney transplants? Provide a reason.
8. Tests were performed on patients A, B, C, and D. Results from the tests are provided in **Table 2**. The results obtained for patient A are considered normal.

**Table 2** Test Results for Four Patients

| Patient | Blood pressure (mmHg) | Cardiac output (L/min) | Glucose in urine (g/100 mL) | Urine output (mL/24 h) |
|---|---|---|---|---|
| A | 120/70 | 5.0 | 0.00 | 1500 |
| B | 130/80 | 5.5 | 0.00 | 1700 |
| C | 115/70 | 4.5 | 0.06 | 1950 |
| D | 90/55 | 3.0 | 0.00 | 500 |

   (a) Which patient could have a circulatory problem?
   (b) Explain how a circulatory problem could affect urine output.
   (c) Explain why the urine output of patient C is elevated.
9. Alcohol is a diuretic, a substance that increases the production of urine. Alcohol suppresses the production and release of ADH. Should people who are prone to developing kidney stones consume alcohol? Explain.
10. In some countries, kidneys are sold for transplant. Do you believe that this practice is acceptable? Explain your answer.

## INVESTIGATION 12.1

### *Do Sports Drinks Really Work?*

Sweating helps to cool the body while exercising. Drinking water during and after exercising helps to restore water balance, but does not, according to many sports drinks advertisers, enable the body to continue operating at peak athletic performance. Sugar and electrolyte levels must be restored. Sugars provide the fuel for cellular respiration. Electrolytes, such as $K^+$ and $Ca^{2+}$, are essential for nerve and muscle function.

Nerve and muscle function can be measured by monitoring changes in reaction time. In this investigation, you will design ways to test the effects of a sports drink on reaction time.

**Report Checklist**

| | | |
|---|---|---|
| ○ Purpose | ● Design | ● Analysis |
| ● Problem | ● Materials | ● Evaluation |
| ● Hypothesis | ● Procedure | ○ Synthesis |
| ● Prediction | ● Evidence | |

### Purpose

To determine the effect of sports drinks on reaction time

### Hypothesis/Prediction

(a) Predict what effects, if any, that sports drinks will have on reaction time. Record your prediction, and describe the criteria you used in making your prediction.

### Design

(b) Design a controlled experiment to test your hypothesis. Include the following in your design:

- descriptions of the manipulated, responding, and controlled variables
- a step-by-step description of the procedure, including the steps for measuring reaction time (one possibility for measuring reaction time is given below)
- a list of safety precautions
- a table to record observations

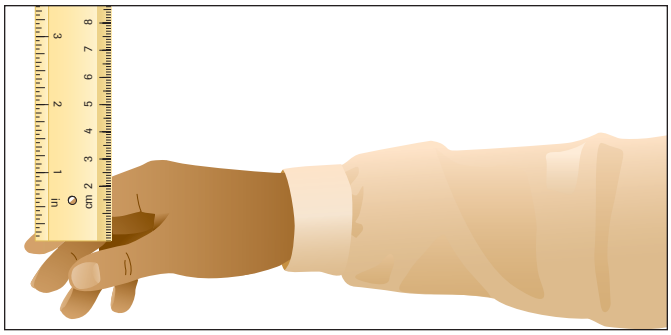

**Figure 1**
Starting position of ruler

### Procedure

1. Submit your procedure, safety precautions, data table, and list of materials and apparatus to your teacher for approval. The procedure for measuring reaction time is given below. For the rest of the procedure, use your own approved design.

### Measuring Reaction Time

2. Ask your subject to place his or her forearm flat on the surface of a desk. The subject's entire hand should be extended over the edge of the desk.
3. Ask the subject to place his or her index finger and thumb approximately 2 cm apart. Hold a 30-cm ruler vertically between the thumb and forefinger of the subject. The lower end of the ruler should be even with the top of the thumb and forefinger (**Figure 1**).
4. Indicate when ready, and release the ruler within the next 30 s. Measure the distance the ruler falls before being caught between the subject's thumb and forefinger. Repeat twice more and calculate the average. Repeat the procedure for the left hand. Record your data in a table.

### Analysis

(c) Explain how the sports drink affected reaction time.

(d) Explain how the data confirmed or disproved your prediction.

### Evaluation

(e) Describe any problems you encountered while carrying out the procedure.

(f) Describe how you could improve your current design.

(g) Reaction time is affected by other factors, such as anticipation. If you were to repeat this experiment, what new factors would you investigate? Write a brief description of the new procedure.

# INVESTIGATION 12.2

## *Diagnosis of Kidney Disorders*

The identification of proteins and sugars in urine samples can reveal kidney disease. This investigation will involve the use of simulated urine samples to test for indications of disease.

Biuret reagent can be used to identify proteins. It reacts with the peptide bonds joining amino acids together, producing colour changes from blue, indicating no protein, to pink or purple.

Benedict's solution can be used to identify reducing sugars. In this investigation, it will be used to detect glucose in the urine. **Table 1** summarizes the quantitative results obtained when reducing sugars, such as glucose, react with Benedict's solution.

**Table 1** Reducing Sugar and Benedict's Solution Reactions

| Colour of Benedict's solution | Approximate % of sugar |
|---|---|
| blue | negative |
| light green | 0.5–1.0 |
| green to yellow | 1.0–1.5 |
| orange | 1.5–2.0 |
| red to red–brown | > 2.0 |

### Purpose

To determine which of the samples have characteristics that indicate kidney disease

### Materials

safety goggles
laboratory apron
4 urine samples (simulated), labelled W, X, Y, and Z in dropper bottles
4 small test tubes
wax pencil
distilled water in wash bottle
Benedict's solution (in small dropper bottle)
test-tube clamp
hot water bath
test-tube brush
Biuret reagent (in small dropper bottle)
hydronium pH paper

**Safety goggles and a laboratory apron must be worn for the entire laboratory. Handle hot objects and their contents carefully to avoid burns.**

**Benedict's solution is toxic and corrosive. Biuret reagent is toxic. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eye, rinse your eye for at least 15 min and inform your teacher.**

**Report Checklist**

| | | |
|---|---|---|
| ○ Purpose | ● Design | ● Analysis |
| ● Problem | ○ Materials | ● Evaluation |
| ● Hypothesis | ○ Proceduree | ● Synthesis |
| ● Prediction | ● Evidence | |

### Procedure

1. Label four test tubes W, X, Y, and Z. Place 20 drops of urine sample W in test tube W. Repeat the procedure for samples X, Y, and Z in their respective test tubes.
2. Add 10 drops of Benedict's solution to each test tube and, using a test-tube clamp, place the test tubes in a hot water bath (approximately 80 °C).
3. Observe for 6 min. Record any colour changes in a table. Use **Table 1** to identify the values for each sample. Record the values in the table.
4. Wash each of the test tubes and dry them before beginning the protein test.
5. Use your four labelled test tubes. Place 20 drops of each urine sample in its respective test tube. Add 20 drops of Biuret reagent to each of the test tubes, then tap the test tubes with your fingers to mix the contents. Record your results in a table.
6. Use hydronium paper to determine the pH of each sample. A chart is usually located on the pH paper dispenser. Record your results in the table.
7. Clean up your work space. Dispose of all chemicals as directed by your teacher.
8. Wash your hands thoroughly.

### Analysis

(a) Which sample indicates diabetes mellitus? Provide your reasons.

(b) Which sample indicates diabetes insipidus? Give reasons for your response.

(c) Which sample indicates nephritis? Provide reasons for your answer.

(d) Which sample indicates a tremendous loss of body water while exercising? Provide your reasons.

### Synthesis

(e) What are recommended treatments for diabetes mellitus and diabetes insipidus?

(f) Why is nephritis difficult to treat?

# Chapter 12 SUMMARY

## Outcomes

### Knowledge

- identify the principal structures of the excretory system, i.e., kidneys, ureters, urinary bladder, and urethra (12.1)
- explain the structure and function of the nephron, including the glomerulus, Bowman's capsule, tubules, loop of Henle, collecting duct, afferent and efferent arterioles, and capillary net, and explain their functions in maintaining plasma compositions, i.e., water, pH, and ions (12.1)
- describe the function of the kidney in excreting metabolic wastes and expelling them into the environment (12.1)
- identify the role of antidiuretic hormone (ADH) and aldosterone in water reabsorption and excretion (12.1, 12.2)

### STS

- explain that the goal of science is knowledge about the natural world (12.2)
- identify the role of antidiuretic hormone (ADH) and aldosterone in water reabsorption and excretion (12.1, 12.2)

### Skills

- ask questions and plan investigations (12.1, 12.2)
- conduct investigations and gather and record data and information by researching and creating a flow chart to describe how humans maintain homeostasis with respect to water and ions (12.1)
- analyze data and apply mathematical and conceptual models by: observing the principal features of a mammalian excretory system and identifying structures from drawings obtained from various print and electronic sources (12.1); collecting and interpreting data in analysis of simulated urine, identifying limitations of data, comparing to theoretical values, and producing a generalization (12.1, 12.2); and making analogies between kidney function and renal and peritoneal dialysis (12.2)
- work as members of a team and apply the skills and conventions of science (all)

## Key Terms

### 12.1

deamination
urea
uric acid
ureter
urethra
cortex
medulla
renal pelvis
nephron
afferent arteriole
glomerulus
efferent arteriole
peritubular capillary
Bowman's capsule
proximal tubule
loop of Henle
distal tubule
collecting duct
threshold level
interstitial fluid

## MAKE a summary

1. Create a flow chart or diagram that shows how the excretory system maintains an internal equilibrium through the exchange of matter and energy with the environment. Label the diagram with as many of the key terms as possible. Check other flow diagrams and use appropriate designs to make your sketch clear.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

## Go To www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 12
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

## EXTENSION

CBC radioONE QUIRKS & QUARKS

**Pig Cell Transplants**

Dr. David White discusses the controversy of a new technique of transplanting insulin-producing islet cells into diabetics. The procedure would allow diabetics to cut down, or even stop their daily shots. The controversy stems from the fact that the islet cells come from seven-day-old piglets.

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## UNIT 20 D PERFORMANCE TASK

### Determining Fitness Level

In this Performance Task, you will design and carry out a fitness test. This test will indirectly indicate the amount of oxygen being delivered to your tissues.

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**Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.**

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**DO NOT WRITE IN THIS TEXTBOOK.**

## Part 1

1. The site of filtration in the kidney occurs between the
   A. renal artery and renal vein
   B. glomerulus and Bowman's capsule
   C. distal tubule and collecting duct
   D. renal artery and glomerulus

2. The normal sequence of processes in the formation of urine is
   A. reabsorption, secretion, filtration
   B. secretion, reabsorption, filtration
   C. filtration, reabsorption, secretion
   D. active transport, reabsorption, filtration

3. Identify the area in **Figure 1** in which the reabsorption of glucose takes place.
   A. W
   B. Y
   C. X
   D. Z

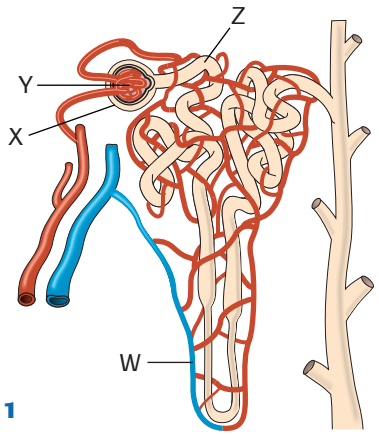


**Figure 1**

4. The following are structures of the excretory system:
   NR
   1. ascending limb of the loop of Henle
   2. ureter
   3. renal pelvis
   4. Bowman's capsule

   List the numbers of the structures in the order in which urine passes through them. (Record all four digits of your answer.)

## Part 2

5. **Sketch** a labelled diagram that shows the following parts of the excretory system: kidney, renal artery, renal vein, ureter, bladder, and urethra. **Describe** the function of each organ.

6. **Figure 2** is a diagram of a nephron. Write a unified
   DE response that addresses the following aspects of this structure:
   - **Identify** which letters indicate the afferent and efferent arterioles.
   - **Explain** how an increase in blood pressure in B would affect the functioning of the kidney.
   - **Explain** why proteins and blood cells are found in B but not in D.
   - **Identify** the area of the nephron where you would expect to find the greatest concentration of glucose.
   - **Identify** the area(s) in which $Na^+$ ions are actively transported.
   - **Identify** the area of secretion.
   - **Identify** the area(s) of the nephron where you would expect to find urea?
   - In which area of the nephron would you expect to find cells with a great number of mitochondria? **Justify** your answer.

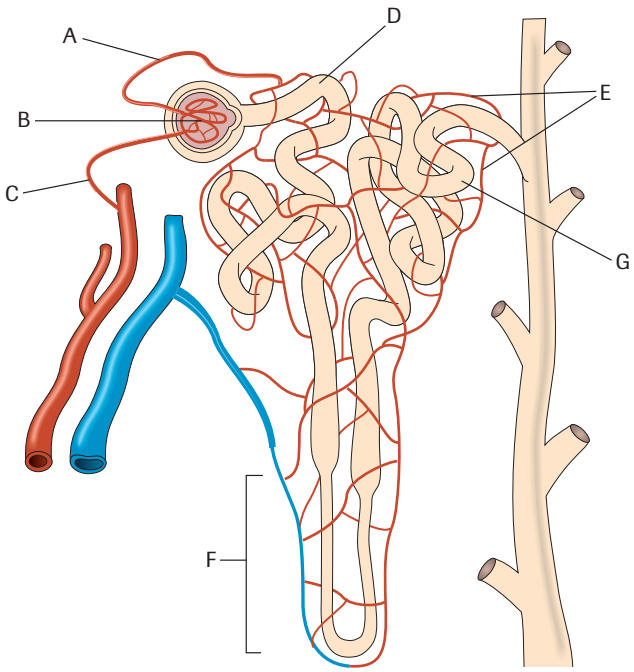


**Figure 2**

7. The following processes occur in the formation and excretion of urine once the blood has entered the kidney. List these subsequent processes in the order in which they occur.
   (a) urine is stored in the bladder
   (b) blood enters the afferent arteriole
   (c) fluids pass from the glomerulus into the Bowman's capsule
   (d) urine is excreted by the urethra
   (e) $Na^+$ ions, glucose, and amino acids are actively transported from the nephron
   (f) urine passes from the kidneys into the ureters

Use the following information to answer questions 8 to 10.

A micropipette was used to extract fluids from various structures within the kidney. The data in **Table 1** show an analysis of the fluids.

**Table 1** Concentration of Substances in Kidney Fluids

| Substance found in fluid | Blood plasma from afferent arteriole | Glomerular filtrate from Bowman's capsule | Urine |
|---|---|---|---|
| protein | 7.00 | 0.00 | 0.00 |
| urea 0.04 | 0.04 | 2.00 | |
| glucose | 0.10 | 0.10 | 0.00 |
| sodium ions | 0.32 | 0.32 | 0.35 |
| chloride ions | 0.38 | 0.38 | 0.60 |

Quantities are in g/100 mL.

8. DE According to the data provided, which substance is not filtered from the blood into the Bowman's capsule? **Justify** your answer.

9. DE Which substance provides evidence of secretion? **Justify** your response.

10. DE Which substance provides evidence of reabsorption? **Justify** your answer.

11. A pH analysis reveals that the urine of humans fluctuates between acidic and basic depending on the diet. **How** does the kidney help to maintain a constant blood pH?

12. A drug causes dilation of the afferent arteriole and constriction of the efferent arteriole. **Describe how** the drug will affect urine production.

13. **Why** do the walls of the proximal tubule contain so many mitochondria?

14. Athletes now undergo random urine testing for drugs. From your knowledge of excretion, **describe** the pathway of substances such as drugs through the urinary system, from the time they enter the glomerulus until they are excreted in the urine.

15. A drug that inhibits the formation of ATP by the cells of the proximal tubule is introduced into the nephron. **How** will the drug affect urine formation? Provide a complete physiological explanation.

16. A blood clot lodges in the renal artery and restricts blood flow to the kidney. **Explain why** this condition leads to high blood pressure.

17. For every 100 mL of salt water consumed, 150 mL of body water is lost. The solute concentration found in seawater is greater than that found in the blood. **Explain** in physiological terms **why** this loss of body water occurs. (*Hint:* Consider the threshold level for salt reabsorption by the cells of the nephron.)

18. **Predict** how a drop in blood pressure would affect urine output. **Justify** your prediction.

19. **Outline** in a chart the advantages and disadvantages of the following:
   (a) hemodialysis
   (b) peritoneal dialysis
   (c) kidney transplants by living donors and cadaver donors

Use the following information to answer questions 20 and 21.

**Figure 3** outlines a dialysis procedure.

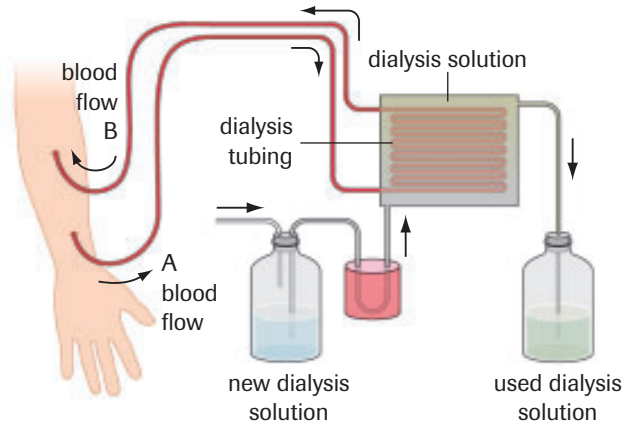


**Figure 3**

20. DE **Describe** what happens to the concentration of urea in the blood in **Figure 3**, as blood moves through blood vessel A, through the dialysis tubing, and into blood vessel B.

21. DE For effective dialysis to occur in **Figure 3**, will wastes move by active transport or by diffusion? **Identify** which fluid must contain the lower concentration of wastes: the blood or the dialysis solution.

## Extension

22. **Design** an efficient kidney for an animal living in a desert.

**Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.**

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**DO NOT WRITE IN THIS TEXTBOOK.**

## Part 1

Use the following information to answer questions 1 and 2.

In a study, a volunteer fasted for 12 hours, and was then given 300 g of food. Blood samples were taken before she ate, then once an hour for 9 h. The concentrations of fatty acids, glucose, and amino acids in the blood were determined. **Figure 1** is a graph of this data.

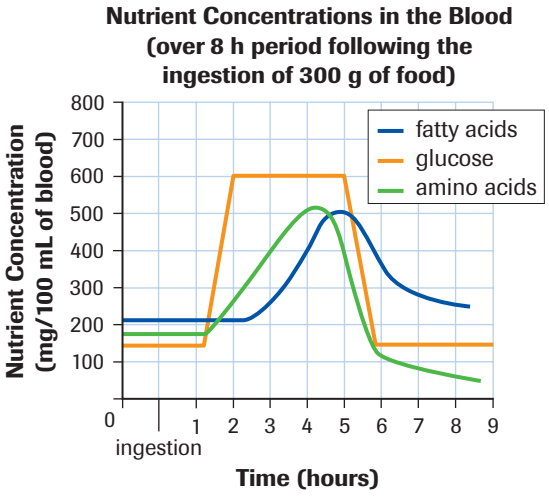



**Figure 1**

1. According to the data in **Figure 1**, the most difficult food to chemically break down and use for energy is
   A. fat
   B. protein
   C. carbohydrate
   D. amino acids

2. Identify how long after ingestion the maximum concentration of amino acids and fats in the blood occurred.
   A. amino acids, 1h; fats, 3h
   B. amino acids, 2h; fats, 4h
   C. amino acids, 4h; fats, 5h
   D. amino acids, 5h; fats, 8h

3. Identify the reason why the backwash of bile salts into the stomach can lead to stomach ulcers.
   A. Bile salts are very acidic and corrosive to cells. Cells that line the stomach are destroyed by acids.
   B. Bile salts can emulsify the mucosal layer, which is composed of proteins and lipids. Unprotected cells are digested.
   C. Bile salts convert pepsinogen into pepsin, which begins digesting proteins in the cells of the stomach's lining.
   D. Bile salts can digest the mucosal layer, which is composed of proteins and vitamins. Unprotected cells are digested.

4. Correctly complete the following statement: A heart attack will result from lack of nutrients and oxygen to the heart muscle, due to a blockage by atherosclerosis of the
   A. pulmonary arteries
   B. coronary arteries
   C. pulmonary veins
   D. coronary veins

5. Identify which of the following respiratory volumes cannot be measured directly using a respirometer.
   A. tidal volume
   B. expiratory reserve volume
   C. inspiratory reserve volume
   D. vital capacity

6. Identify which of the following is not involved in the immune system's second line of defence.
   A. helper T cells
   B. chemotaxis
   C. phagocytosis
   D. pseudopods

7. Identify the process by which gases move from the alveoli into the capillaries.
   A. active transport
   B. osmosis
   C. filtration
   D. diffusion

8. Correctly complete the following statement: Complete separation of the pulmonary and systemic circulation systems is necessary to provide
   A. increased cardiac output
   B. more efficient operation of the lungs
   C. more efficient oxygenation of the blood
   D. increased ventricular contractions

9. Identify the statement that correctly describes how breathing rate is regulated.
   A. The heart controls the breathing rate by monitoring oxygen levels.
   B. The heart controls the breathing rate by monitoring carbon dioxide levels.
   C. The brain controls the breathing rate by monitoring oxygen levels.
   D. The brain controls the breathing rate by monitoring carbon dioxide levels.

Use the following information to answer questions 10 and 11.

Fluid samples were taken from different parts of the nephron (samples W, X, and Y). The concentration of urea, glucose, and protein in each sample was then determined, and recorded in **Table 1**.

**Table 1** Composition of Fluid Samples from Nephron

| Component | Sample W (g/100 mL) | Sample X (g/100 mL) | Sample Y (g/100 mL) |
|---|---|---|---|
| urea | 0.03 | 0.03 | 2.00 |
| glucose | 0.10 | 0.10 | 0.00 |
| protein | 0.007 | 7.00 | 0.00 |

**10.** Identify the part of the nephron from which sample X was likely taken.

A. The glomerulus: there is a higher protein concentration because very few proteins pass through the glomerulus.
B. The distal tubule: there is a lower concentration of urea because most of the water is absorbed in the distal tubule.
C. The collecting duct: there is a lower concentration of urea because water is not reabsorbed.
D. The proximal tubule: glucose is found in the proximal tubule because the glomerulus is permeable to glucose.

**11.** Identify the parts of the nephron from which samples W and Y were taken.

A. Sample W is from the distal tubule; sample Y is from the collecting duct.
B. Sample W is from the loop of Henle; sample Y is from Bowman's capsule.
C. Sample W is from the loop of Henle; sample Y is from the distal tubule.
D. Sample W is from Bowman's capsule; sample Y is from the collecting duct.

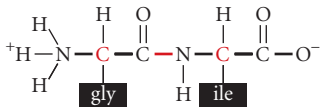
**12.** During muscle contraction

A. the sarcomeres lengthen, and actin and myosin fibres shorten
B. the sarcomeres shorten, and actin and myosin fibres lengthen
C. the sarcomeres lengthen, but actin and myosin fibres do not change in length
D. the sarcomeres shorten, but actin and myosin fibres do not change in length

Use the following information to answer questions 13 and 14.

These four numbered structures are examples of different classes of nutrients used by the human body.

1

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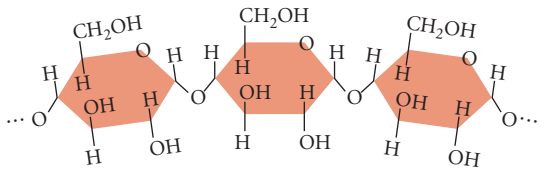

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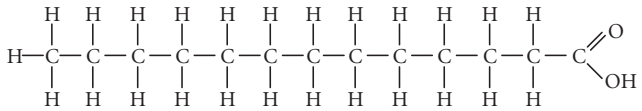

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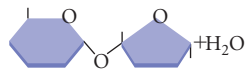


**13.** NR Match the number of each of the structures with its description. Use each number only once. (Record all four digits of your answer.)

_____ _____ _____ _____

disaccharide fat dipeptide polysaccharide

**14.** NR Match the number of each of the structures with its enzyme below. Use each number only once. (Record all four digits of your answer.)

_____ _____ _____ _____

sucrase amylase lipase protease

## Part 2

**15.** **Identify** the blood vessel that is being referred to in each of the following statements:

(a) This blood vessel is the site of diffusion of oxygen and nutrients.
(b) This blood vessel has the highest blood pressure.

**16.** **Figure 2** (next page) shows the components of the human respiratory system. **Identify** the structure by number and name that is described in each of the following statements:

(a) This muscular structure relaxes during exhalation, causing the volume of the chest cavity to decrease.
(b) This structure conducts air into the left lung.
(c) This structure prevents food from entering the trachea.
(d) Inhalation and exhalation are indicated by pressure changes within these structures.

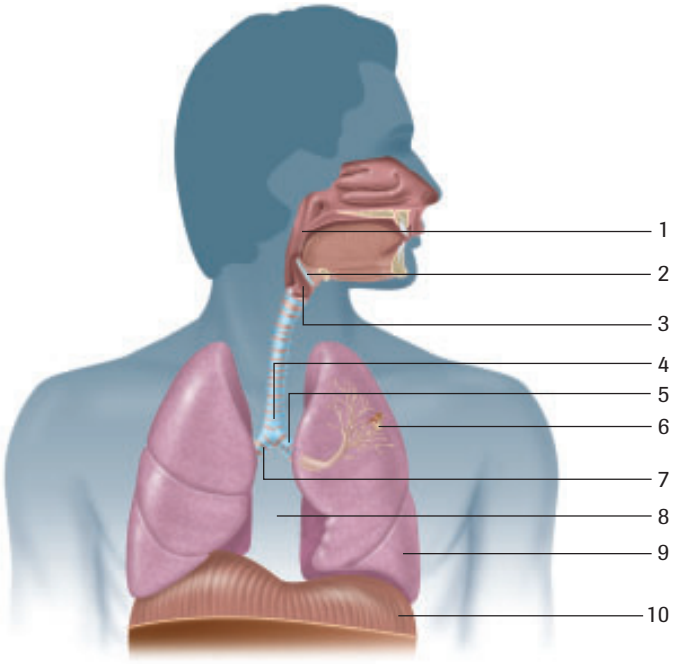


**Figure 2**

Use the following information to answer questions 17 and 18.

Amylase digestion of starch is tested by the experiment shown in **Figure 3**. Each of the flasks is filled with 100 mL of 4 % starch suspension. A 1 % amylase solution is added to flask 1. The amylase solution is boiled for 2 min then added to flask 3.

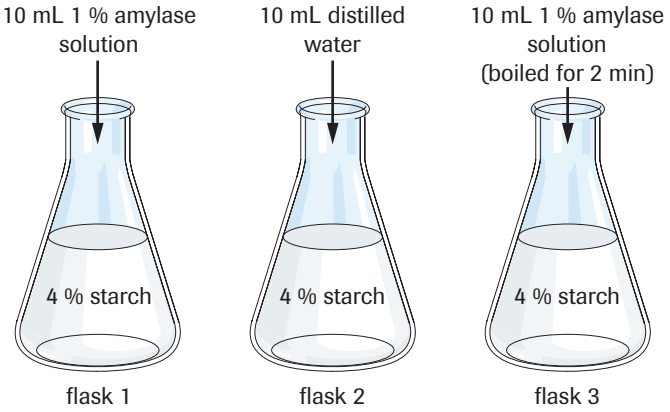


**Figure 3**

**17.** **Identify** the control in this experiment.
DE

**18.** Iodine was added to the flasks after 10 min. **Predict** in
DE which flask(s) the blue–black colour, indicating the presence of starch, would likely be observed. **Explain why**.

**19.** The money spent on cancer treatment continues to
DE escalate every year. One politician has suggested that medical problems caused by inappropriate lifestyle choices should be given a lower priority for treatment. Write a unified response that addresses the following aspects of life style and health.

- **Identify** two diseases that could be reduced by changing lifestyles.
- **Evaluate** the politician's statement. Should money be used first to treat people who have not contributed to their own health problem? **Justify** your answer.

Use the following information to answer questions 20 to 23.

Pancreatin is a commercially prepared mixture of the components of the pancreas, including trypsin and lipase. An experiment was conducted to determine the effect of pancreatin and bile on the digestion of egg yolk. Egg yolk contains lipids and proteins. The scientist placed 10 g of egg yolk in each of four test tubes and incubated them at 37 °C for 24 h. As shown in **Table 2**, the pH of the solution was recorded at the beginning of the experiment and after 24 h. The degree of digestion is indicated by plus signs (+).

**Table 2** Experimental Data for the Digestion of Egg Yolk

| Test tube | Initial pH | Pancreatin | Bile | pH after 24 h | Amount of digestion |
|---|---|---|---|---|---|
| 1 | 9 | no | no | 9 | none |
| 2 | 9 | ✓ | no | 7 | +++ |
| 3 | 9 | no | ✓ | 9 | + |
| 4 | 9 | ✓ | ✓ | 6 | ++++ |

**20.** **Identify** which test tube acted as a control. **Describe** what
DE the control indicates.

**21.** **Explain why** the pH of the solution changes after 24 h in
DE test tubes 2 and 4.

**22.** **Explain why** test tube 4 shows a greater amount of
DE digestion than test tube 2.

**23.** **Interpret** the results of test tube 3.
DE

Use the following information to answer questions 24 to 27.

Hemoglobin and myoglobin are two proteins that carry oxygen. Myoglobin, found in muscle cells, has the ability to combine with one molecule of oxygen. Hemoglobin, found in red blood cells, has the ability to combine with four oxygen molecules. **Figure 4**, on the next page, shows the ability of hemoglobin and myoglobin to combine with oxygen at varying partial pressures.

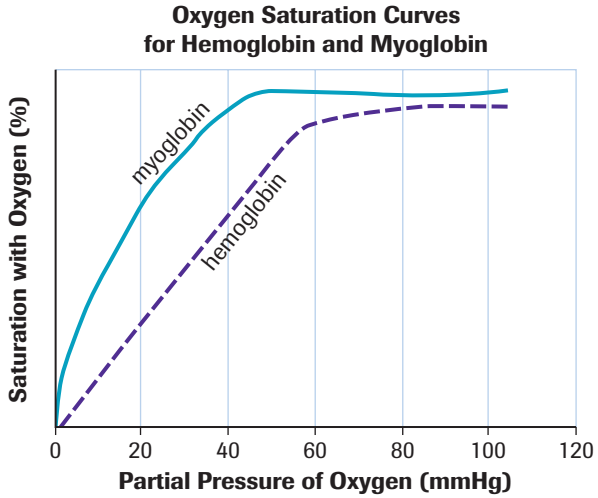


**Figure 4**

**24.** **Identify** the protein that accepts oxygen more readily.
DE

**25.** **Identify** the partial pressure at which hemoglobin becomes saturated.
DE

**26.** **Identify** the partial pressure at which myoglobin becomes saturated.
DE

**27.** **Describe** the adaptation for exercise by comparing the saturation curves for hemoglobin and myoglobin.
DE

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**28.** **List** all types of T and B lymphocytes and explain the role of each in the immune response.

**29.** A glass of milk contains lactose, proteins, butterfat (mostly triglycerides), vitamins, and minerals. **Describe** what happens to each component in your digestive tract.

**30.** Often, holiday meals are larger than regular meals and have a higher fat content. After eating a holiday meal, you may feel uncomfortably full for longer than normal. Based on what you have learned about digestion, **describe** in biochemical terms the cause of the discomfort.

**31.** In some forms of heart failure, the left side of the heart is the weaker and fails to perform properly, while the right side continues to pump blood into the lungs with near normal vigour. Write a unified response addressing the following aspects of this form of heart failure:
DE
- **Explain why** fluid flows from the lung capillaries into the alveoli and bronchioles of the lungs, resulting in a condition called pulmonary edema.
- **Describe** the effect of pulmonary edema on the normal functioning of the lungs.
- **Describe** a possible technological solution for this condition.

**32.** Prolonged starvation reduces the amount of protein in the blood. One consequence of this is an increased amount of tissue fluid, which tends to gather in the abdomen and lower limbs. Write a unified response addressing the following aspects of this increase in tissue fluid:
DE
- **How** is this related to capillary fluid exchange?
- Indicate a possible reason **why** scientists have been unable to solve the problem.

**33.** **Define** muscle tetanus.

Use the following information to answer questions 34 to 37.

Lung cancer is the leading cause of cancer death in both men and women in Canada. It is also a disease that can be prevented. Controllable environmental factors seem to stimulate cancer-causing genes over a period of time to become active, causing cells to develop into lung cancer. Interpret the information presented in **Figure 5**.

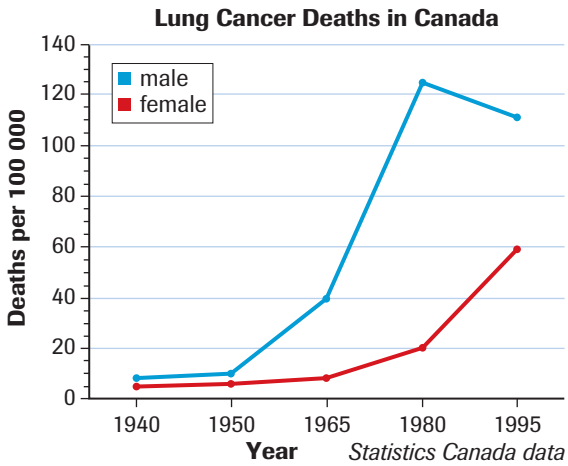


**Figure 5**

**34.** In the early 1920s, shortly after the First World War, smoking became fashionable for men. **Hypothesize** why lung cancer rates did not increase until the 1950s.
DE

**35.** Suggest a reason **why** no comparable increase occurred in lung cancer in women during the same period. **Justify** your answer.
DE

**36.** **Predict** trends in lung cancer over the next 10 to 20 years.
DE

**37.** **Compare** the trends between males and females between 1980 and 1995.
DE

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**38.** About 80 % of runners land on the outer part of their foot and roll inward. This action helps absorb the shock, but for people whose foot bends more than 10 degrees, the action can lead to problems. Conduct research on running shoes that correct for pronation, or excessive foot roll. **How** have running shoe manufacturers attempted to prevent injuries?

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**39.** Review the focusing questions on page 236. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.